Citation:
Dobbin, N and Hunwicks, R and Jones, B and Till, KA and Highton, J and Twist, C (2018) Criterion and Construct Validity of an Isometric Mid-Thigh Pull Dynamometer for Assessing Whole Body Strength in Professional Rugby League Players. International Journal of Sports Physiology and Performance, 13 (2). pp. 235-239. ISSN 1555-0273 DOI: https://doi.org/10.1123/ijspp.2017-0166

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Title: Criterion and construct validity of an isometric mid-thigh pull dynamometer for assessing whole body strength in professional rugby league players

Short Title: Validity of an isometric mid-thigh pull dynamometer

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Abstract Word Count: 216

Manuscript Word Count: 2463

Figures: 2

Tables: 4

ABSTRACT

Purpose: The purpose of this study was to examine the criterion and construct validity of an isometric mid-thigh pull dynamometer to assess whole body strength in professional rugby league players.

Methods: Fifty-six male rugby league players, (33 senior and 23 youth professional players) performed four isometric mid-thigh pull efforts (i.e. two on the dynamometer and two on the force platform) in a randomised and counterbalanced order.

Results: Isometric peak force was underestimated ($P<0.05$) using the dynamometer compared to the force platform (95% LoA: -213.5 ± 342.6 N). Linear regression showed that peak force derived from the dynamometer explained 85% (adjusted R^2 = 0.85, SEE = 173 N) of the variance in the dependent variable, with the following prediction equation derived: predicted peak force = [1.046 * dynamometer peak force] + 117.594. Cross-validation revealed a non-significant bias ($P>0.05$) between the predicted and peak force from the force platform, and an adjusted R^2 (79.6%), that represented shrinkage of 0.4% relative to the cross-validation model (80%). Peak force was greater for the senior compared to youth professionals using the dynamometer (2261.2 ± 222 cf. 1725.1 ± 298.0 N, respectively; $P<0.05$).

Conclusion: The isometric mid-thigh pull assessed using a dynamometer underestimates criterion peak force but is capable

of distinguishing muscle function characteristics between professional rugby league players of different standards.

Keywords: Peak force, measurement error, talent identification, collision sport, evaluation.

INTRODUCTION

Maximum muscle strength is an important physical quality for rugby league that is related to fundamental performance characteristics (e.g. sprint performance, tackling ability)[1,2,3] and is associated with a lower risk of injury.[4] Maximal strength is also known to differentiate between playing standard,[5-7] meaning it has importance as part of talent identification. Practitioners must therefore be able to accurately assess a rugby league player's whole body maximal strength.

The assessment of maximal strength using isoinertial measures (e.g. 1RM squat) is traditionally used in rugby league,[1,6,8,9] but can be influenced by individual technique and experience.[10] Isointerial dynamometry is also associated with an increased risk of injury,[11] while testing with large squads can be time consuming. Taken together, the shortcomings of isoinertial dynamometry suggest that practitioners must think carefully about the selection of a valid, safe and time-efficient measure of maximal strength.

The use of the isometric mid-thigh pull offers a method of maximal strength assessment that meets the aforementioned criteria.[12-14] The mid-thigh pull requires participants to stand on a force platform with an immovable bar positioned to correspond with the second-pull clean position, just below the crease of the hip.[15] Participants are then instructed to pull as fast and hard as possible, enabling various kinetic measures to be quantified from ground reaction forces.[16,17] With good reliability[15,18,19] and strong relationships with dynamic actions such as sprinting and jumping,[3,17] the isometric mid-thigh pull presents a useful method for assessing whole-body maximum strength. However, the utility of the method is likely to be limited by the availability of a force platform.[17]

The development of a custom-built isometric mid-thigh pull dynamometer offers a more cost effective method for the safe and time-efficient measure of maximal strength. However, for practitioners it is important to understand the validity of any new device against the criterion method,[20] whilst it must be capable of differentiating between those of different training status (i.e. construct validity).[21] In a recent study by James et al.,[19] isometric mid-thigh pull performance measured using a strain gauge had good reliability (coefficient of variation = 3.1%) but poor criterion validity when compared against the same exercise conducted on a force platform. In this study, validity was assessed using a relatively small sample size of recreationally active participants (n = 15) and no attempt was made to understand the ability of the simplified apparatus to differentiate peak force capabilities between athletes of different training status (i.e. construct validity). Accordingly, the purpose of this study was twofold: 1) to compare the peak forces obtained in a group of professional rugby league players during the isometric mid-thigh pull between a custom built dynamometer and a force platform (i.e. criterion validity); and 2) to establish the utility of the isometric mid-thigh pull to differentiate muscle strength characteristics between rugby league players of different standards (i.e. construct validity).

METHODS

Participants and design

With institutional ethics approval and participant consent, 56 male rugby league players were recruited from two professional clubs and classified as senior professional (n = 33, age 25.3 ± 3.4 years, stature 183.9 ± 6.8 cm, body mass 97.9 ± 9.5 kg) and youth professional (n = 23, age 18.3 ± 1.4 years, stature 179.2 ± 5.2 cm, body mass 86.2 ± 8.2 kg) players. Senior players had completed at least one season training for, and competing in, the Super League competition. Youth consisted of players who were currently playing at Academy level or who had in the last three months graduated to the first team. Data were collected in the pre-season period with all players having at least two years of systematic resistance training experience that involved lower body maximum lifts. After habituation, each player completed two isometric mid-thigh pull strength assessments on the dynamometer and force platform in a randomised cross-over design with a five-minute passive recovery between each effort. All testing was carried out indoors on a hard, non-slip surface.

Methods

All participants completed a standardised warm up before the mid-thigh pull that comprised of five minutes of dynamic stretching along with two isometric efforts at 50% and 75% of maximal effort.[22] For both measurements, participants were positioned similar to the second pull phase of the power clean, with the bar located mid-way between the knees and hips, knees flexed at ~140 degrees and shoulders over the bar.[23] Based on previous literature, participants were given a 3 second countdown and instructed to pull as fast and hard as possible for 5 seconds, placing emphasis on the rate of force development, which is reported to aid maximal force development.[24]

Dynamometer: A custom-built isometric mid-thigh pull dynamometer was designed and built to include a T.K.K.5402 dynamometer (Takei Scientific Instruments Co. Ltd, Niigata, Japan) sampling at 122 Hz. Briefly, this consisted of a wooden platform (80 x 50 cm) with rubber foot grips (31 x 20 cm), placed shoulder width apart and chain (51 cm) from the dynamometer to a latissimus pulldown bar (120 cm; Decathlon, United Kingdom; see Figure 1b). The chain length was adjusted to allow participants to achieve the position described above. Before pulling, participants applied minimal pre-tension to the chain to avoid any jerking action on initiating the lift. The highest peak force (kgf) from the two attempts was then multiplied by 9.81 (to represent the value in Newtons) and subsequently used for analysis.

Force Platform: The isometric mid-thigh pull was performed using a commercially available portable force platform (HUR Labs, FP4, Tampere, Finland) with a sampling rate of 1200 Hz. The force plate was seated in a customized fixed rack, which enabled adjustments in bar height by 3 cm increments (Figure 1a). Where necessary, smaller adjustments in bar height were made by placing 1 cm wooden boards on the force platform. In such instances the force platform was then re-calibrated before any measurement was performed. Each participant's best trial from two attempts, as determined by the highest peak force (PF) in Newtons (N), was used for analysis.[22]

*** INSERT FIGURE 1 HERE***

Statistical Analyses

Data were initially checked for normality via the Shapiro-Wilk statistic (P>0.05) before using Pearson product-moment correlations (r-value) to check for heteroscedastic errors and assess the relationship between methods. Paired sample *t*-tests were used to calculate differences (biases) between means of measurement methods (criterion validity) and followed up using 95% limits of agreement (95% LoA)[25] to quantify the within-subject variation (random error). Effect sizes (ES) and 90% confidence intervals [lower bound – upper bound] were also used to quantify the magnitude of the effect between methods and groups using the following criteria: 0.2, 0.6 and 1.2 for small, moderate and large effects, respectively.[26] Linear regression analysis was used to determine a prediction equation for peak force along with the typical regression statistics (R^2 and SEE). Using an 80/20% split of the sample,[27] we cross-validated the prediction equation and sought to establish that there was minimal shrinkage in the R^2 value relative to the model. This being the case, the full predictive model can be presented. To determine the sensitivity of the IMTP against an analytical goal, an independent *t*-test was used to assess between-group differences in peak force (construct validity) and normalised peak force using ratio (PF/BM) and allometric (PF/BM^b) scaling, where PF represents peak force, BM is body mass in kilograms and b is a power exponent.[28] Within-session reliability was determined using coefficient of variation (CV) and intraclass correlation coefficient (ICC). Data are reported as mean and standard deviation(s) and analysed using SPSS for

Windows (Version 23.0, 2015) and a predesigned spreadsheet.[29]

RESULTS

Within-session reliability revealed CVs of 8.3% and 9.2%, and ICCs of 0.913 and 0.912 for the dynamometer and force platform, respectively.

Isometric peak force was significantly underestimated (P<0.001, ES = -0.53 [-0.85 - -0.21] using the dynamometer compared to the force platform, with 95% of the differences ranging between -556.1 and 130.1 N. However, there was a strong, significant relationship for peak force between the dynamometer and force platform (r = 0.92, P<0.001) (Table 1, Figure 2).

INSERT TABLE 1 HERE

*** INSERT FIGURE 2 HERE***

The regression analysis based upon the cross-validation sample (Table 2) revealed that peak force derived from the dynamometer explained 80% (adjusted R^2 = 0.80) of the variance in the dependent variable, yielding the equation: predicted peak force = (1.046 * dynamometer peak force) + 117.594. Cross-validation analysis revealed no significant difference (P=0.724, ES = 0.05 [-0.26 - 0.36] between the predicted and observed peak force from the force platform, and an adjusted R^2 (79.6%) that represented a shrinkage of 0.4% relative to the cross-validation model (80%, Table 3). Therefore, the predictive power of the model was not substantially changed when applied to a different sample.

INSERT TABLE 2 HERE

INSERT TABLE 3 HERE

The overall regression model (Table 4) revealed that peak force measured on the dynamometer explained 84.2% of the variance in the dependent variable (SEE = 173 N). The equation was: peak force (N) = (1.089*dynamometer peak force) + 31.95.

INSERT TABLE 4 HERE

Peak force was greater for the senior compared to youth professionals using both the force plate (2532.7 ± 242.5 cf. 1855.3 ± 325.1 N, respectively; t = 8.93, P<0.001, ES = 2.36 [1.96 - 2.76] and the modified dynamometer (2261.2 ± 222.0 cf. 1725.1 ± 298.0 N, respectively; t = 7.66, P<0.001, ES = 2.04 [1.66 - 2.42]. Due to the large difference in body mass (ES 1.32 [0.98 – 1.66], peak for+0.34ce data were scaled to account for this difference. Senior players generated significantly greater force compared to youth with both ratio (26.07 ± 3.08 cf. 21.58 ± 3.71 N/kg, t = 4.936, P<0.001, ES = 1.32 [0.98 – 1.66] and allometric scaling (23.44 ± 2.63 cf. 19.46 ± 3.35 N/kg$^{1.02}$, t = 4.828, P<0.001, ES = 1.32 [0.98 – 1.66] applied. Similarly, peak force was greater for the senior players compared to youth on the dynamometer for ratio (23.25 ± 2.63

cf. 20.04 ± 3.25 N/kg, t = 4.069, P<0.001, ES = 1.09 [0.76 – 1.42] and allometrically (21.88 ± 2.50 cf. 18.89 ± 3.07 N/kg$^{1.01}$, t = 4.01, P<0.001, ES = 1.07 [0.74 – 1.40] scaled values.

DISCUSSION

This study sought to compare the peak force obtained during the isometric mid-thigh pull performed on a customised dynamometer and a force platform in a group of professional rugby league players (i.e. criterion validity). Additionally, comparisons between two playing standards (senior and junior professionals) were made to determine the construct validity of the isometric mid-thigh pull for use with rugby league players. The principle finding of this study was that the isometric mid-thigh pull performed on a custom-built dynamometer underestimated peak force from a force platform as evidenced by the significant difference and small effect size. However, there was a strong relative agreement between both measurement methods. As such, a regression equation was developed that could correct this 'average' underestimation. Finally, the modified dynamometer was able to differentiate peak force between playing standards suggesting it possesses appropriate construct validity in the measurement of muscle function characteristics of senior and youth professional rugby league players.

There was poor agreement between peak force measurements during an isometric mid-thigh pull on the modified dynamometer and the force platform. The mean difference in peak force achieved between the two methods indicated that the modified dynamometer was, on average, -213.5 N lower compared to the force platform. This is consistent with the systematic bias (-229.1 N) between similar apparatus reported by James et al.[19] When the 95% LoA were considered, a player with a peak force of 2000 N measured during an isometric mid-thigh pull using a force platform could, in the worst-case scenario, achieve a value between 1444 and 2129 N using the modified dynamometer. To provide context, this potential error (~685 N) is larger than improvements in peak force derived from an isometric mid-thigh pull after a nine-week maximal strength or power training programme (431-608 N [30]). This means it would be difficult to detect meaningful changes in mid-thigh pull performance when using the modified dynamometer and, therefore, when small-to-moderate changes are expected, practitioners might consider using a regression equation or force platform.

The underestimation in peak force observed in the present study might be explained by the more open-chain design of the modified dynamometer compared to that of the force platform. During the force platform trials, peak ground reaction force was measured through the feet in contact with the force platform and force applied vertically in a single plane. In contrast, the modified dynamometer required participants to 'pull' vertically on a bar anchored centrally, which due to its design had a large degree of anterior-posterior and medio-lateral movement. It is possible that this movement allowed participants lean back into the pull, resulting in force being applied outside of the vertical axis.[19] It is also possible that the superior sampling frequency of the force platform compared to the modified dynamometer (1200 cf. 122 Hz, respectively) influenced the precision of the peak force measurements.[15]

To correct for the underestimation of peak force using the modified dynamometer, we have developed a regression equation that reduces the difference from the force platform to within mean values of ~4.6 N. Therefore, when a comparison between methods is necessary, this equation can be applied to data collected from the modified dynamometer when using a similar sample to that used in this study. However, practitioners should note that there might be some error in this estimate of ~173 N in individual cases, owing to some of the variance in force platform performance not being explained by performance using the modified dynamometer.

In this study, players of a higher standard, who are deemed to be stronger from more extensive resistance training exposure,[6] performed better on the isometric mid-thigh pull using both methods. More specifically, peak force measured on the modified dynamometer for senior professional rugby league players was 31% higher than that of youth professionals, similar to the difference of ~36% according to the force platform. Furthermore, our results indicated that this large difference in peak force was irrespective of differences in body mass. After applying both ratio and allometric scaling, the results indicated that senior players outperformed youth players regardless of body mass, suggesting training history is an important factor when assessing peak force. As such, the modified dynamometer mid-thigh pull is sufficiently sensitive to be used to classify the strength capabilities of professional rugby league players of different standards and training histories.

Practical Applications

A criterion measure of peak force during an isometric mid-thigh pull cannot be measured from a modified dynamometer. This notwithstanding, the dynamometer is capable of distinguishing differences in muscle function between more and less experienced rugby league players. For those practitioners who require more accurate measures of peak force from isometric-mid thigh pull, they might choose to use the regression equation provided. It is important to note that the prediction equation for peak force is specific to rugby league players and caution should be taken when applying this to other populations. Strength and conditioning coaches who wish to measure maximal strength when profiling rugby players might adopt this safe, cost-effective and valid apparatus.

Conclusion

The current study investigated the criterion and construct validity of a modified dynamometer for the assessment of isometric mid-thigh pull strength. Where practitioners are required to profile players (i.e. talent identification), the use of a modified dynamometer can be used to differentiate between academy and first-grade professional rugby league players. Additionally, the regression equation provided can allow practitioners to detect training-induced changes in whole-body strength, albeit they should be cognisant that small changes are likely to go undetected, and in such cases, a force platform should be used.

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Table 1. Concurrent validity of the dynamometer against the force platform for measuring peak force.

	Dynamometer peak force (N)	Force platform peak force (N)	95% LoA	CV%	Pearson's *r* value
Peak force (N)	2041.0 ± 367.5*	2254.5 ± 435.5	-213.5 ± 342.6	19.3	0.92

*Note: * = significantly lower (P<0.05) than peak force derived from force platform. LoA = limits of agreement. CV% = coefficient of variation.*

Table 2. Overall parameters of the cross-validation prediction model using the dynamometer to estimate peak force (N) derived from the force platform (*n* = 45).

Predictor Variable	Unstandardized coefficient		Standardized coefficient	
	B	Standard Error	Beta	*t*-value
Constant	117.594	161.600		*0.0728*
Dynamometer peak force (N)	1.046	0.079	0.897	*13.302***

Note: Adjusted R^2 *= 0.800; ** = P<0.001.*

Table 3. Cross-validation of predicted and observed force platform peak force (*n* = 11)

	Predicted Peak Force	Force platform peak force (N)	95% LoA	CV%	Adjusted R^2
Peak force (N)	2344.3 ± 319.6	2362.8 ± 388.0	-4.60 ± 352.56	14.73	0.796

*Note: predicted force platform peak force = (1.046 * Dynamometer peak force) + 117.594.*

Table 4. Overall parameters for the prediction model using peak force derived from the dynamometer (N) to estimate force platform peak force (N) (n = 56).

Predictor Variable	Unstandardized coefficient		Standardized coefficient	
	B	Standard Error	Beta	*t*-value
Constant	31.950	131.816		*0.242*
Dynamometer Peak Force (N)	1.089	0.064	0.919	*17.127***

Note: Adjusted R^2 *= 0.842; ** = P<0.001.*

Figure 1. Isometric mid-thigh pull performed on the force platform (A) and modified dynamometer (B).

Figure 2. Relationship between the dynamometer and force platform for measuring peak force.

1